Gaussberg rift – illusion or reality?

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Summary Radio-echosounding and RADARSAT mosaic data provide new evidence for rifted crust in Princess Elizabeth Land, East Antarctica. The arcuate Gaussberg rift consists of two sub-parallel depressions separated by segmented horst-like escarpments. The rift is about 500 km long and its width varies from 60 km in the south-western part to 150 km near the West Ice Shelf. The Gaussberg rift, part of the Lambert rift system, was probably initiated in the Permian at the same time as the Lambert sub-meridional rift zone with deposition of coal-bearing Permian rocks. The Gaussberg rift probably exploited a weak zone between the Proterozoic mobile belt and Vestfold-Rauer cratonic block.

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Geological background

The geology of the eastern part of Princess Elizabeth Land (PEL) is known from two outcrops. (1) Mount Brown consists of a lower migmatitic garnet gneiss, overlain by 100 m of agmatitic pyroxene plagioclase schist with interlayered garnet schist, and a top 10 m of migmatitic pyroxene plagioclase schist with interlayered garnet gneiss and blocks of diopside rock (Ravich et al., 1968). The crust was formed and metamorphosed at c. 1360 Ma (Mikhalsky et al., 2001). (2) Mount Gaussberg, on the coast at 57°S, 89°E, is an isolated, 369-m-high volcanic cone, the product of subglacial eruption (Phillipi, 1912; Vyalov and Sobolev, 1959; Tingey et al., 1983). Its highly potassic leucitites (Sheraton and Cundari, 1980) belong to the comparatively rare potassium-rich mafic volcanic suite. Murphy et al. (2002) classified these ultrapotassic mantle-derived volcanic rocks as lamproites, and considered them as the youngest lamproite occurrence (56±5 ka) yet recognized on the Earth.

Rift structure

Radio-echosounding (RES) data collected in 2005 by the Polar Marine Geological Research Expedition (PMGRE) over the eastern part of Princess Elizabeth Land reveal a bedrock topography of linear depressions and rises that form a continuous linear structure of complex configuration. The structure can be traced (by using the RADARSAT data; Jezek, 1999) to Mount Gaussberg on the Leopold and Astrid Coast where the Pleistocene volcano of Mount Gaussberg is located (Figure 1). The structure consists of two sub-parallel depressions separated by segmented horst-like rises (escarpments). One of these segments is Mount Brown, which reaches a height of 1982 m.

The available RES data along coastal regions of PEL (Lythe et al., 2000) are inadequate for characterizing the morphological features of all the rift shoulders (Figure 2). But in some places, we can interpret horsts and grabens from the RADARSAT mosaic data. This is true not only for the Mount

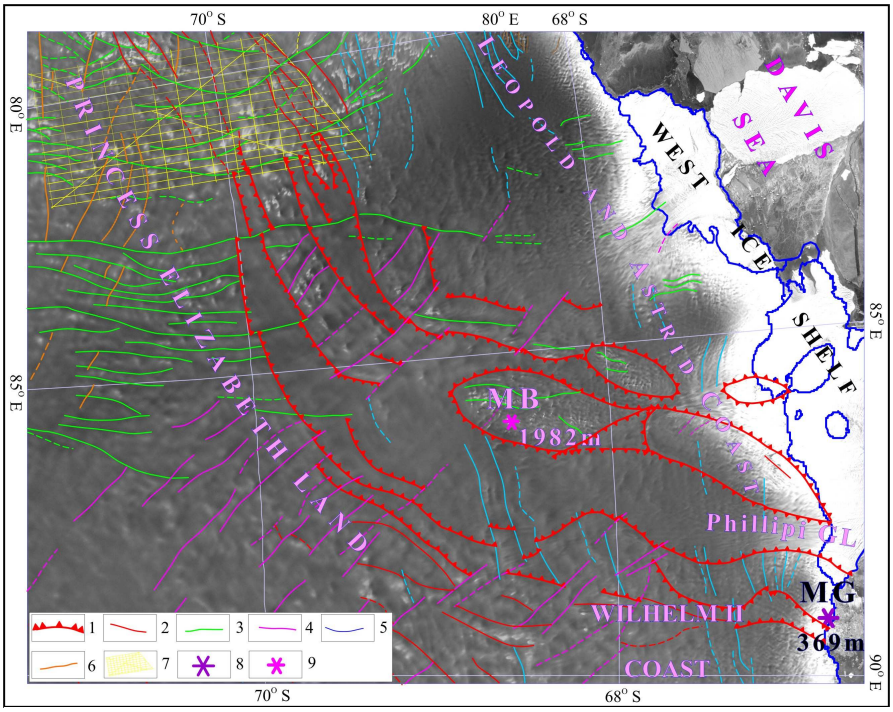

Figure 1. Structural elements of the proposed Gaussberg rift derived from the RADARSAT Antarctic Mapping Project (RAMP) mosaic of Antarctica (Jezek, 1999). 1 – normal faults defining the rift, 2 – faults conformal to the rift, 3 - NS transverse lineaments, 4 – NW-SE lineaments, 5 – E-W lineaments, 6 – WNW-ESE lineaments, 7 – aerogeophysical survey area of the PMGRE, 8 – location of Mount Gaussberg (MG), 9 – location of Mount Brown (MB).

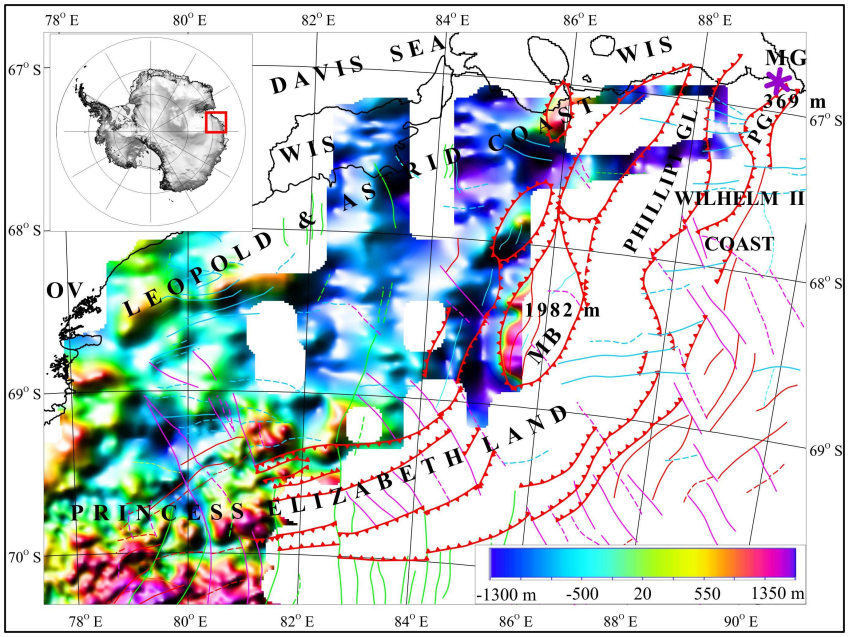

Figure 2. Bedrock topography map of Princess Elizabeth Land. Gaussberg Rift structural elements are the same as on Figure 1. The insert shows the location of study area in Antarctica. Mb – Mount Brown, BG – Mount Gaussberg, OV – Oasis Vestfold, PG – Posadowsky Glacier, WIS – West Ice Shelf.

Brown horst, outlined by the 1000 m asl contour line, but also for other positive morphological features. Depressions reach more than 800 m bsl near the West Ice Shelf and within the central graben occupied by the Phillipi Glacier.

The rift is about 500 km long, and including its western continuation of short (fragmented) faults may exceed 700 km. The width of the central horst system averages about 50 km; that of the central depression is from 10-12 km in the southwestern part, and 70-75 km alongside Mount Brown. The width of the Gaussberg rift system varies from 60 km in the south-western area to 150 km near the West Ice Shelf.

We suggest that the Gaussberg rift extends beneath the Davis Sea shelf, but without seismic data this suggestion is entirely speculative. The wide basement depression beneath the continental slope and abyssal plain of the Davis Sea Basin (Leitchenkov & Guseva, 2006) may represent the offshore continuation of the Gaussberg rift (Figure 3) between the Kerguelen Plateau and Bruce Rise.

The Lambert Glacier and Prydz Bay grabens together with the Princess Elizabeth Trough and the Davis Sea depression, with total length exceeding 2700 km, may form one of the largest riftogenic belts of our planet. This rift system is a result of large-scale extension which occurred in East Antarctica in the Permian - Early Cretaceous prior to East Gondwana break-up (Powell et al., 1988).

Discussion

Information for other rifts in Antarctica and along its margin indicate the age of the Gaussberg rift, its tectonic relation to the Lambert-Prydz system and similar structures of Gondwana, and the geologic history of this segment of East Antarctica and Gondwana as a whole. The radio-echosounding (Lythe et al., 2000), gravity (Aleshkova, 2005), and RADARSAT mosaic data (Jezek, 1999) for the Prince-Charles Mountains, Princess Elizabeth Land and its continental margin, and the Gamburtsev Subglacial Mountains show that the Gaussberg rift is interrelated by lineaments or short faults to the Lambert Rift system (Figure 3).

The Lambert Rift is correlated with Indian counterparts (Fedorov et al. 1982; Stagg, 1985; Sheraton et al., 1995; Mishra et al., 1999). For example, Fedorov et al.'s (1982) reconstruction aligns the Lambert Graben with the Mahanadi Valley of eastern India. The present-day form of this structure developed as a failed rift during the break-up of Gondwana. It seems increasingly likely that the Lambert Graben has reactivated a much older structure developed during Grenvillian time at c. 1000 Ma.

Holdgate et al. (2005) and Harrowfield et al. (2005) argue that this correlation is inconsistent with the petrology and rank of coals from the two drainage systems, with regional Gondwana reconstructions, and with the width of the relict Antarctic shelf. Instead, they align the Lambert Graben with the Godavari Valley, and the Mahanadi Valley with a parallel belt of coal-bearing basins in the Rajmahal Hills, ~650 km northeast, corresponding to two postulated accommodation zones of East Antarctica (Figure 4). Our study shows that these postulated zones correspond to the Gaussberg rift and to a system of continuous fault zones of the Denman and Scott Glaciers. If these correlations are correct, then both Antarctic counterparts may contain coal-bearing deposits.

The Denman Glacier and Bunger Hills regions have a Precambrian history followed by Carboniferous emplacement of trachytic dykes (Ravich et al., 1968; Sheraton et al., 1995). The dykes reflect extension when intracontinental grabens in the Lambert Glacier area and in India and Australia were formed. According to Sheraton et al. (1995), the Denman Glacier defines the southerly extension of the Perth Basin Rift. Both structures define major geological discontinuities and there are marked similarities in geological histories of terranes to the east (Mesoproterozoic metamorphic rocks of the Bunger Hills area and Albany Mobile Belt) and west (Neoproterozoic-Cambrian metamorphic and plutonic rocks of

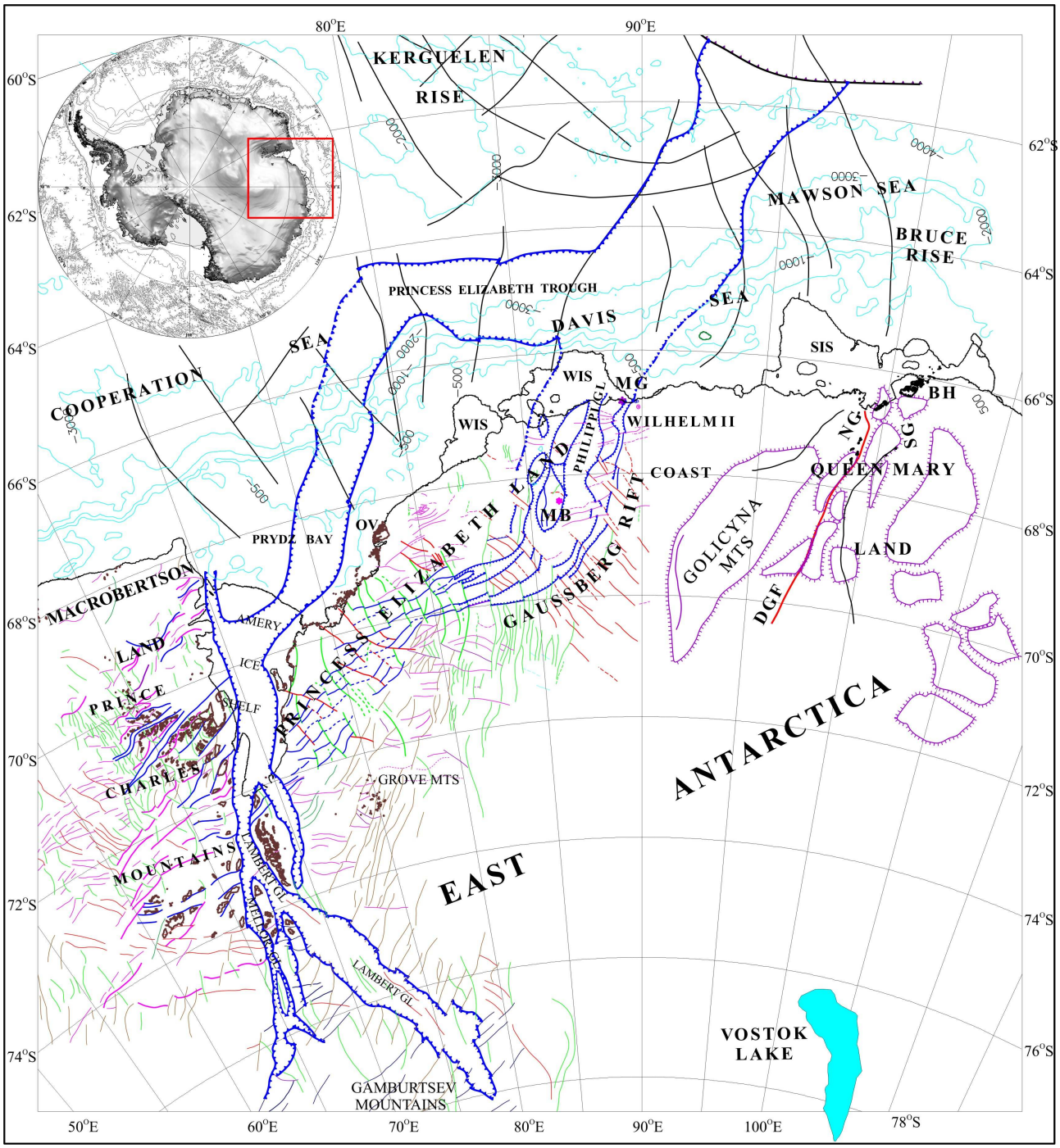

Figure 3. The structure of the Lambert rift system (LRS) including the Gaussberg Rift identified in this study by using the geophysical data and the RADARSAT information. Major elements of the LRS are shown by blue colour. Variously trending lineaments or faults are shown by different colours. Major horsts of the Denman and Scott Glaciers area are shown by purple colour. The insert shows the location of the study area in Antarctica. BH – Bunger Hills, DGF Denman Glacier Fault, MB – Mount Brown, MG – Mount Gaussberg, NG – Northcliffe Glacier, OV – Oasis Vestfold, SG – Scott Glacier, SIS – Shackleton Ice Shelf, WIS – West Ice Shelf.

the Denman Glacier area and Leeuwin Block). It should be mentioned that sedimentation of the Sandow Group in a coastal-continental environment (Ravich et al., 1968) is consistent with continental collision followed by ensialic rifting. The Sandow Group may have been deposited at c. 500-600 Ma, in association with mafic intrusive and extrusive activity. Extensive syenitic to granitic plutons, with post-orogenic or anorogenic (A-type) chemical characteristics, were

emplaced at 516 Ma (Sheraton et al., 1995). A-type magmatism in some other terranes appears to be an early manifestation of continental rifting (Anderson and Cullers, 1978).

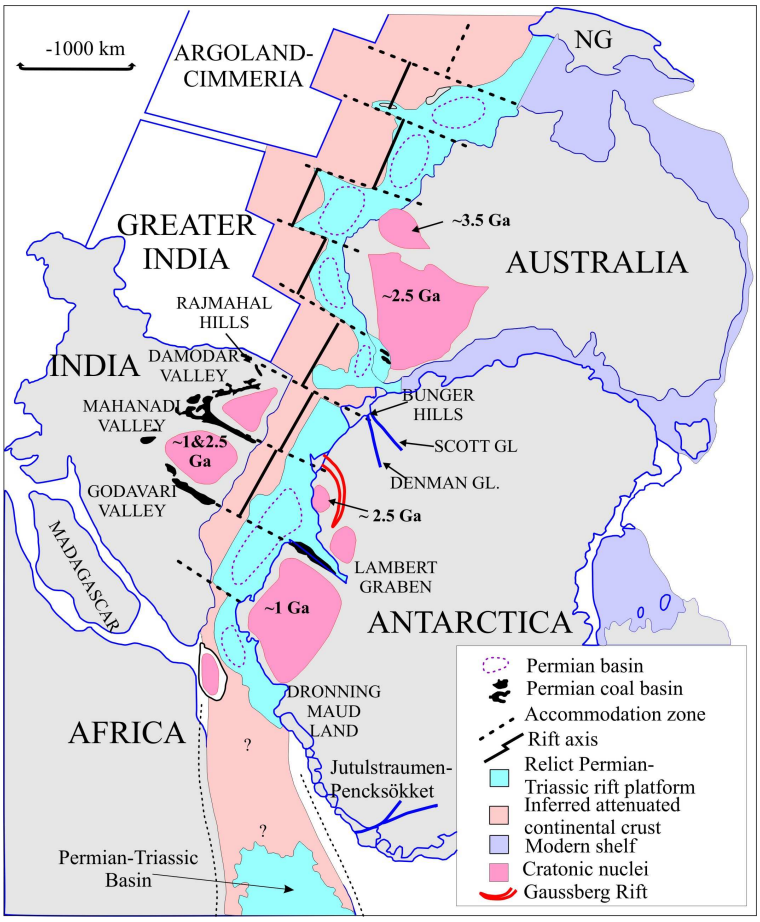

Figure 4. Reconstruction of Permian-Triassic Gondwana (after Harrowfield et al., 2005 with modifications), illustrating separation of Indian and Antarctic platforms, alignment of Lambert graben and Godavari Valley, Mahanadi Valley and Gaussberg Rift, and compartmentalization of intracontinental rift. NG – New Guinea.

Preliminary analysis of the RADARSAT imagery shows that the Denman Glacier occupies a linear fault system (> 400 km), whereas southward continuation of the Scott Glacier area represents a continuous system of horsts that bound a wide central depression (Figure 3). The Scott Glacier together with graben-like structures hidden under ice-cover and with the graben underlying of Lake Vostok possibly represents a long rift system generated by an extensional event prior to the breakup of Gondwana.

Continental rifts may inherit pre-existing basement structure or adapt to them by forming knee-jointed and zigzag combinations when the old anisotropic basement fractures along lines of weakness (Rosendahl, 1987). The Gaussberg rift probably inherited the tectonically weak zone of the Proterozoic mobile belt along its boundary with the Vestfold-Rauer cratonic block.

The Jutulstraumen-Pencksökket rifts of western Dronning Maud Land, related to Jurassic extension events, were formed at the boundary between an Archean craton, called the Grunehogna Province, and the Late Proterozoic to Cambrian mobile belt, called the Maudheim Province (Allen, 1991; Moyes et al., 1993; Golynsky et al., 2000; Perritt and Watkeys, 2003).

Conclusions

Radio-echosounding and the RADARSAT data acquired over the eastern part of PEL reveal a structure at least 500 km long called the Gaussberg rift. The rift was probably initiated at the same time as the Lambert graben, marked by the deposition of coal-bearing Permian sediment. We speculate that the Gaussberg rift may be considered as a hypothetical accommodation zone of the Carboniferous-Permian intracontinental rift along 4000 km of the west Australian and east Indian margins, which filled with thick Permian-Triassic sediment including alluvial coals.

The Gaussberg rift is part of the Lambert rift system, interrelated by lineaments or short faults. The Lambert rift system consists of 5-6 segments and can be delimited over the continent and its continental margin. The total length of the rift system exceeds 2700 km, of the same scale as the African-Arabian, Rhine-Libyan and Baikal systems (e.g. Milanovsky, 1976; Rosendahl, 1987). The Gaussberg rift exploited an inherited weakness between the Proterozoic mobile belt and Vestfold-Rauer Archean cratonic block at wavelengths appropriate to the scale and eventual width of the developing rift.

The Mahanadi Valley and a parallel belt of coal-bearing basins in the Rajmahal Hills of East India speculatively correspond respectively to the Gaussberg rift and to a system of continuous fault zones of the Denman and Scott Glaciers, and have potentially coal-bearing deposits and other mineral resources. They can be considered as major sources of terrigenous sediments on the PEL continental margin where current-controlled drift deposits are recognized in seismic data (e.g. Leitchenkov & Guseva, 2006). The Scott Glacier together with graben-like structures hidden by ice and with the graben of Lake Vostok may represent an extensive rift system developed as a result of large-scale pre-breakup extension of Gondwana.

As to the question in the title of this paper, we argue that all available geological and geophysical data point to the existence of the Gaussberg rift, but present knowledge is inadequate to draw any definite conclusions about its origin, evolution, and any current tectonic activity. Also poorly known are the lithospheric dynamics and crustal architecture of

the East Antarctic shield, geology and ice sheet dynamics and geodynamics of rifting in an ice-covered environment. New high-quality airborne geophysical data sets including airborne gravity, magnetic and ice-penetrating radar measurements during the International Polar Year and beyond will bear on this problem. Offshore projects will target the neighboring system in the Davis Sea by acquisition of deep crustal geophysical data. These investigations will provide a basis for international, multidisciplinary integrated initiatives to study the relationship between Antarctic geodynamic processes, ice sheet dynamics, and global environmental change.

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